Comparing Three Geophysical Tools for Assessing the Suitability of Southeast Missouri Soils for Rice Production

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The EM38 meter is an electromagnetic induction (EMI) instrument manufactured by Geonics Limited[1]. With this meter, the depth of penetration is "geometry limited" and is dependent upon intercoil spacing, coil orientation, and frequency. The EM38 meter has a 1 m intercoil spacing and operates at a frequency of 14600 Hz. It has effective penetration depths of about 0.75 and 1.5 m in the horizontal and vertical dipole orientations, respectively.

The GEM300 sensor is an EMI instrument manufactured by Geophysical Survey Systems, Inc.[1] It is configured to simultaneously measure up to 16 frequencies between 330 and 20000 Hz with a fixed intercoil spacing of 1.3 m. With this sensor, the penetration depth is considered "skin depth limited" rather than "geometry limited." The skin-depth represents the maximum depth of penetration and is frequency and soil dependent: a low frequency signal travels deeper through conductive mediums than a high frequency signal. Multi-frequency sounding allows multiple depths to be profiled with one pass.

Also evaluated in this study was the Veris 3100 soil EC mapping system. manufactured by Veris Technologies.[1] This system is a towed, continuous profiling, electrical resistivity unit that injects electrical currents into the soil through coulter-electrodes. This system provides two depths of penetration: one for the upper 0 to 30 cm (shallow) and one for the upper 0 to 90 cm (deep) of the soil. The depth of penetration is "geometry limited" and is dependent upon the spacing and type of electrode array.

[1] Trade names are used to provide specific information. Their mention does not constitute endorsement by USDA-NRCS.

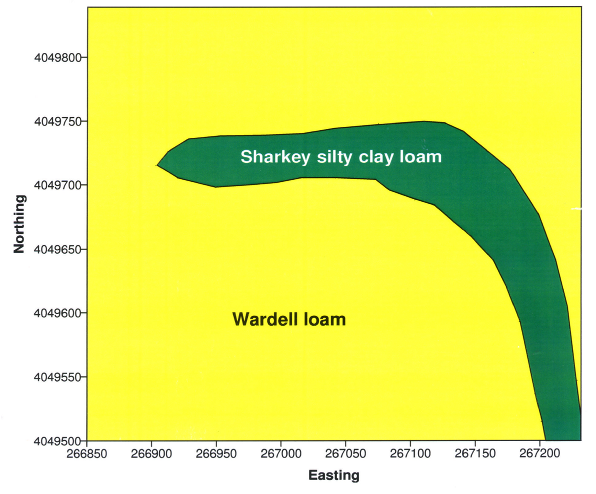
Introduction

Southeast Missouri has experienced an astonishing increase in land dedicated to rice production. Presently, 62,800 to 70,900 hectares are annually planted to rice. Rice is well-suited to the clayey, poorly and very poorly drained soils that have formed on the level floodplain and low terraces of the southern Mississippi River Valley. Slow infiltration of water into these relatively impervious soils enhances the maintenance of a 5- to 10-cm water depth in flood-irrigated rice fields, and improves water use efficiency. However, in many areas of moderately fine- and fine-textured soils, "sand boils" occur as small elliptical inclusions of more rapidly permeable, coarse-textured soils. Because of water management concerns and higher operating and maintenance costs, soils with sand boils are considered marginal land for rice production.

Sand boils vary in size and are not always visible on the ground surface or on aerial photographs. Soil maps prepared by the USDA at scales of 1:15,840 to 1:24,000 do not show in sufficient detail the spatial distribution of sand boils. To meet the needs of rice producers, a new generation of soil maps must be prepared at more appropriate scales (1:6,000 or larger) and show in greater detail the variability of soils across management units. However, unless alternative field methods are developed, these high intensity soil maps will be prohibitively expensive, time-consuming, and labor-intensive to prepare. Alternative methods for mapping soils and soil properties are available. Continuous profiling electrical resistivity (ER) units and electromagnetic induction (EMI) meters are two emerging tools that are being used for high intensity soil surveys and precision farming initiatives. Electromagnetic induction has been used to assess depths to claypans (Sudduth et al., 1995), and to measure soil water contents (Kachanoski et al., 1988), cation exchange capacity (McBride et al., 1990), field-scale, leaching rates of solutes (Jaynes et al., 1995), and as a soil-mapping tool to assist precision farming (Sudduth et al., 1995).

The purpose of this investigation was to evaluate the use of electromagnetic induction and towed array resistivity methods to help assess the average clay content and the suitability of alluvial soils for rice production in southeastern Missouri.

Study Area



Digitized soil map of the study area from the published soil survey report.

The study area (about 13 ha) is in a cultivated field near the town of Howardville, Missouri. It is in an area mapped as Wardell loam and Sharkey silty clay loam (Brown, 1977). The deep, poorly drained Wardell soil formed in loamy alluvium. The Wardell series is a member of the fine-loamy, mixed, thermic Mollic Ochraqualf family (Soil Survey Staff, 1998). The very deep, poorly and very poorly drained Sharkey soils formed in clayey alluvium. The Sharkey series is a member of the very-fine, smectitic, thermic Chromic Epiaquert family (Soil Survey Staff, 1998). The control sections of Wardell and Sharkey soils contain 18 to 35 percent and greater than 60 percent clay, respectively. Soil patterns within the study area are approximated in the figure. The field had been land leveled. Slopes were less than 1 percent.

Field Procedures

The EM38 survey was conducted in a station-to-station mode with a distance between observation points of about 30 m. Survey flags were inserted in the ground at each observation point. This resulted in 162 observation points. Apparent conductivity was measured at each observation point with an EM38 meter placed on the ground surface in both the horizontal and vertical dipole orientations.

The GEM300 sensor was configured to record an observation every 0.5 seconds. This procedure resulted in 11,777 observation points. Measurements were taken with the GEM300 sensor held at hip-height in the vertical dipole orientations only. In-phase, quadrature phase, and conductivity data were recorded at three different frequencies (2010, 9810, and 14610 Hz) at each observation point.

The Veris 3100 soil EC mapping system was pulled behind a pickup truck. Observations were recorded at a rate of one per second. By maintaining a reasonably constant speed of about 8.0 km/hr the number of observations along each traverse line were closely similar. This procedure resulted in 2856 observation points.

For each device, the coordinates of each observation point were recorded with a GPS receiver.

Soil sampling sites were selected to span the observed range in apparent conductivity and to provide reasonable coverage of the soils. At fourteen sampling sites, soil samples were acquired at 25-cm intervals to a depth of 100 cm. For each sample, particle-size was determined by the pipette method. Additional measurements were made with each geophysical device at each sampling site.

Interpretation of Data

The electrical conductivity of soils is influenced by several factors: the types and concentration of ions in solution, the amount and types of clay minerals, the volumetric water content, and the temperature and phase of the soil water (McNeill, 1980). Interpretations of EMI or ER data are based on the identification of spatial patterns within data sets. Though seldom diagnostic in themselves, lateral and vertical variations in apparent conductivity have been used to infer changes in soils and soil properties. On level, graded irrigated fields within the southern Mississippi River Valley, because of comparatively low soluble salt contents and relatively uniform soil moisture contents and water table depths, variations in apparent conductivity were assumed to be principally associated with differences in clay content. Within the study areas, soils with high apparent conductivity were assumed to have more clay than soils with low apparent conductivity. Changes in temperature, the depth to water table, and soil moisture contents will result in temporal variations in apparent conductivity.

Results

Comparison of Apparent Conductivity Data

The spatial distributions of apparent conductivity obtained with the EM38 meter, GEM300 sensor, and Veris 3100 system are shown in Figures 1, 2, and 3, respectively. All three tools produced similar gross spatial patterns of apparent conductivity. Major spatial patterns corresponded with the mapped soil delineations. Spatial patterns principally reflect differences in clay content and soil types. The Sharkey and Wardell soils are texturally dissimilar and have contrasting ranges of apparent conductivity. The high apparent conductivity values in the northeast corner of the study area suggest an area of Sharkey-like soils that was overlooked during soil mapping.

Spatial patterns of apparent conductivity are more intricate than the mapped soil patterns. Higher values of apparent conductivity are associated with greater amounts of clay in the soil and/or shallower depths to finer textured horizons. Each device identified small, included areas of low (< 20 mS/m) apparent conductivity within the Wardell loam delineation. Areas of low conductivity represent coarser-textured soil materials. The number, size, and location of low apparent conductivity areas can be used to assess the field's suitability for rice production, and/or the placement of water control levees.

Data obtained with the GEM300 sensor, although comparable, were slightly higher and more variable than that collected with the Veris 3100 system and the EM38 meter. With the frequencies used in this survey, the GEM300 sensor profiled greater depths than either the Veris system or the EM38 meter. The dissimilarity in measurements among these devices is attributed to differences in system calibration by manufacturers, intercoil and electrode spacing, depth and volume profiled, and frequencies. Two, closely spaced, ½-inch diameter fiber optic cables and a 2½-inch diameter coax cable are buried at a depth of about 120 cm and cross the study area. The GEM300 sensor detected the buried utility cables. The higher apparent conductivity recorded by this sensor reflects, in part, the strong influence of these cables on electromagnetic fields.

Estimation of Clay Contents

At the fourteen sampling sites, responses of the three instruments were compared with the averaged clay content for different depth intervals (see Table 2). With minor exceptions, correlations between average clay content and EMI response improved with increasing soil depth and thickness of the soil column. The strongest relationships with the averaged clay content of these layers ($r = 0.87$ to 0.90) were obtained with the EM38 meter and the Veris 3100 system. For these instruments, the strongest correlations were obtained with the averaged clay content of the 0 to 75 and the 0 to 100 cm layers.

At the fourteen sampling sites, the average clay content within the upper 100 cm of the soil profile was correlated with the response from each instrument by simple linear regression. Because of stronger correlations, only the responses obtained with the EM38 meter in the horizontal dipole orientation (HD), the GEM300 sensor with a frequency of 14610 Hz, and the deep measurements for the Veris 3100 system were used to predict the average clay content of the 0 to 100 cm depth interval (see Table 2). Predictive equations were developed to convert apparent conductivity measurements into estimates of average clay content for the 0 to 100 cm layer ($CC_{0\text{-}100\ cm}$).

These equations provide reasonably accurate predictions of the average clay content in the upper 100 cm of soil. With the EM38 meter and prediction equation [1], the difference between measured and predicted clay contents averaged 5.1 percent and ranged from –9.6 to 12.4 percent. Using the GEM300 sensor with a frequency of 14610 Hz and prediction equation [2], the difference between the measured and the predicted clay contents averaged 6.6 percent and ranged from –16.3 to 20.8 percent. Using deep measurements with the Veris 3100 system and prediction equation [3], the difference between measured and predicted clay contents averaged 5.4 percent and ranged from –12.3 to 10.7 percent.

Figure 4 shows the average clay content for the 0 to 100 cm layer as estimated using the appropriate predictive equation and measurements of apparent conductivity for the three instruments. With the exception of the interference caused in the GEM300 sensor's data by the utility lines, major spatial patterns were similar with each instrument and predictive equation. Spatial patterns evident with each device suggest significant areas within the field having low (<20 percent) clay content. Soils in these areas are more permeable and will not hold ponded water. As a consequence, more water will be required to flood this field, unless a complex pattern of dikes is constructed.

Table 1. Pearson correlation coefficients (r) obtained by the linear regression of clay content and EMI response (mS/m) for selected depth intervals and different instruments, dipole orientations, frequencies, and electrode spacings (N = 14).

	EM38 Meter		GEM300 Sensor			Veris 3100	
Depth Interval	Horizontal	Vertical	2010 Hz	9810 Hz	14610 Hz	Shallow	Deep
0-25 cm	0.6244	0.5447	0.3908	0.5154	0.4612	0.7067	0.5800
0-50 cm	0.8719	0.8174	0.6291	0.6924	0.6632	0.7572	0.8674
0-75 cm	0.9028	0.8722	0.7002	0.7364	0.7141	0.6619	0.8939
0-100 cm	0.8831	0.8723	0.7301	0.7512	0.7472	0.5696	0.8746

Table 2. Prediction equations and associated statistics for estimation of average clay content as a function of apparent conductivity.

Device and operation parameter	Prediction Equation	t-value	probability	
EM38 meter HD	$CC_{0\text{-}100\ cm} = 8.3657 + (0.7704*EM_H)$	6.5211	0.001	[1]
GEM300 sensor 14610 Hz	$CC_{0\text{-}100\ cm} = 11.3147 + (0.4386*14610_{Hz})$	0.4386	0.002	[2]
Veris 3100 system – deep	$CC_{0\text{-}100\ cm} = 8.4545 + (0.5231*Veris_d)$	6.2489	0.001	[3]

Conclusions

Three geophysical tools were used to create detailed maps showing spatial distribution of apparent conductivity across management units in southeast Missouri. Each device produced similar spatial patterns of apparent conductivity. The spatial patterns conformed to mapped soil delineations and were associated with clay content. Moderate correlations were found between apparent conductivity and average clay content. Correlations ($r = 0.39$ to 0.71) were lowest for the surface layer (0 to 25 cm). Correlations improved ($r = 0.63$ to 0.90) as the clay content was averaged over greater depth intervals (0 to 75 cm or 0 to 100 cm). As plotted spatial patterns reflect differences in clay content, these tools can be used to help locate small, included areas of coarser textured soils that might otherwise be overlooked. The number, size, and location of these dissimilar and more rapidly permeable soils determine the suitability of a management unit for rice production.

References:

Brown, B.L. 1977. Soil Survey of New Madrid County, Missouri. USDA-Soil Conservation Service and the Colorado Agricultural Experiment Station. U.S. Government Printing Office, Washington, DC. 70 p.

Greenhouse, J.P., and D.D. Slaine. 1983. The use of reconnaissance electromagnetic methods to map contaminant migration. Ground Water Monitoring Review 3(2): 47-59.

Jaynes, D.B., J.M. Novak, T.B. Moorman, and C.A. Cambardella. 1995. Estimating herbicide partition coefficients from electromagnetic induction measurements. J. Environmental Quality. 24:36-41.

Kachanoski, R.G., E.G. Gregorich, and I.J. van Wesenbeeck. 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68:715-722.

McBride, R.A., A.M. Gordon, and S.C. Shrive. 1990. Estimating forest soil quality from terrain measurements of apparent electrical conductivity. Soil Sci. Soc. Am. J. 54:290-293.

McNeill, J.D. 1980. Electrical Conductivity of soils and rocks. Technical Note TN-5. Geonics Ltd., Mississauga, Ontario. p. 22.

Soil Survey Staff. 1998. Keys to Soil Taxonomy, 8th ed. USDA-NRCS, Washington, DC. 326 p.

Sudduth, K.A., N.R. Kitchen, D.H. Hughes, and S.T. Drummond. 1995. Electromagnetic induction sensing as an indicator of productivity on claypan soils. pp. 671-681. IN: Robert, P.C., R.H. Rust, and W.E. Larson (editors). Proceedings of Second International Conference on Precision Management for Agricultural Systems. Minneapolis, Minnesota. March 27-30, 1994. American Society of Agronomy, Madison, Wisconsin.

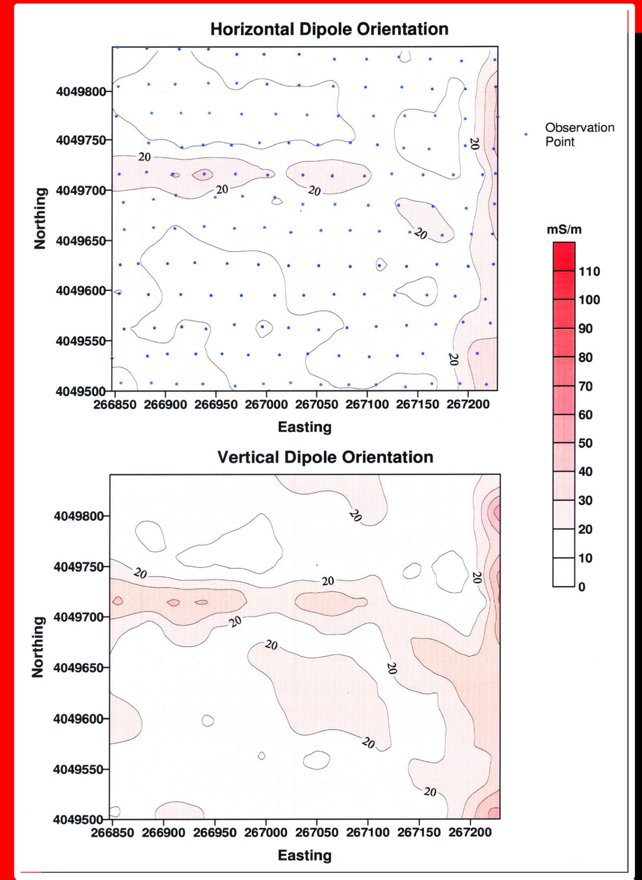


Figure 1. Spatial distribution of apparent conductivity as measured with the EM38 meter in the horizontal (upper plot) and the vertical dipole orientation (lower plot). The locations of observation points are shown in upper plot.

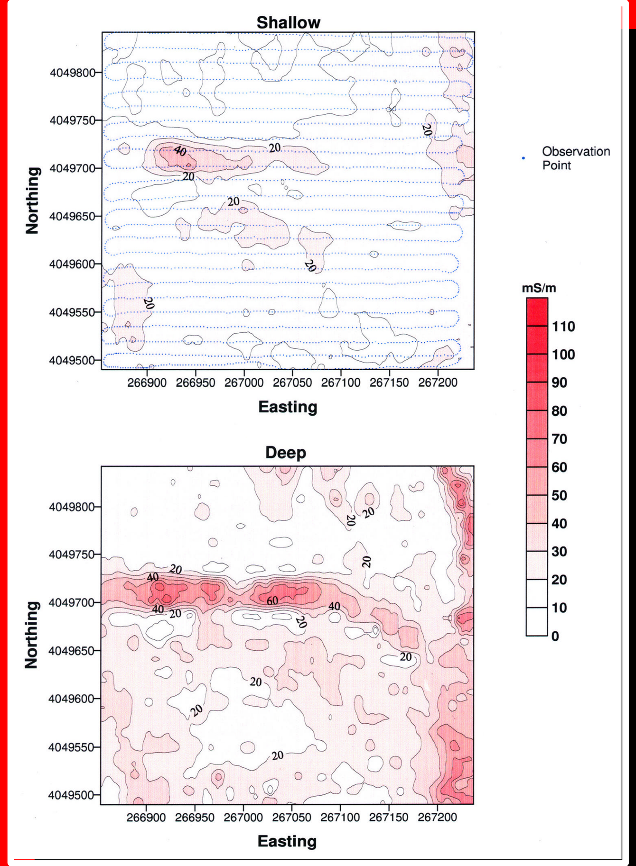


Figure 3. Spatial distribution of apparent conductivity as measured with the Veris 3100 EC soil mapping system in the shallow (upper plot) and the deep (lower plot) modes. The locations of observation points are shown in upper plot.

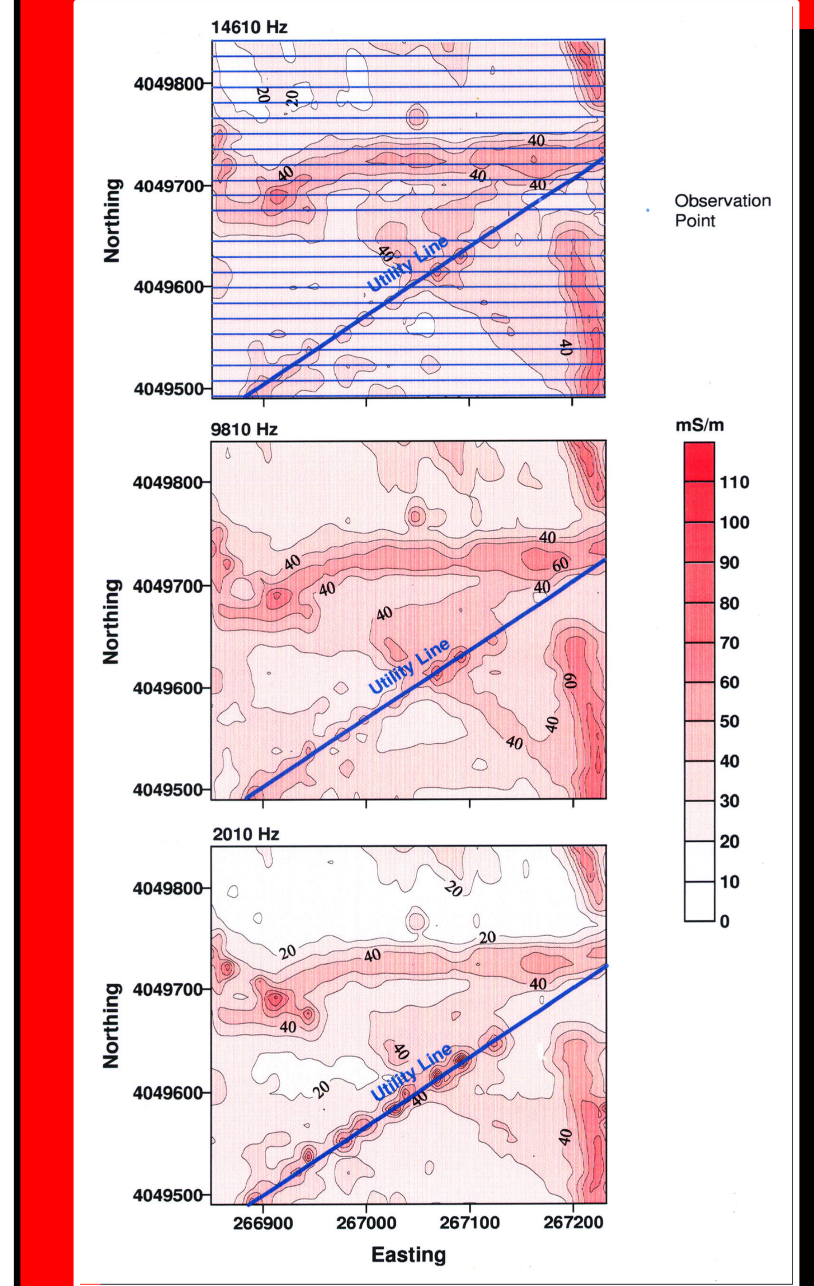


Figure 2. Spatial distribution of apparent conductivity as measured with the GEM300 sensor at frequencies of 14610 (upper), 9810 (middle), and 2010 Hz the vertical (VD) dipole orientation. The locations of observation points are shown in upper plot.

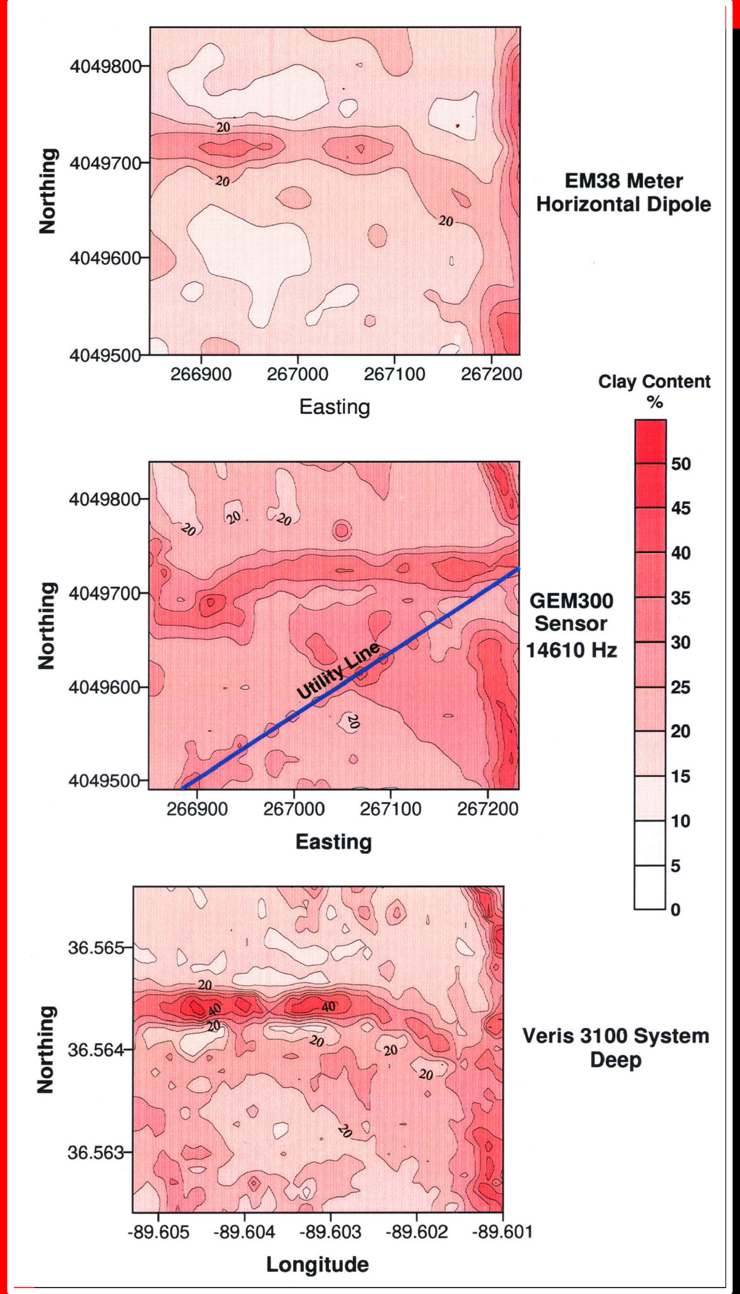


Figure 4. Spatial distribution of the estimated average clay content for the 0 to 100 cm depth interval as predicted from data collected with the EM38 meter in the horizontal dipole orientation (upper), the GEM300 sensor in the vertical dipole orientation at a frequency of 14610 Hz (middle), and the Veris 3100 mapping system in the deep mode (lower).

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